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Apparatus for Stress-Rupture Testing of Filaments in a Controlled Environment

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A stress-rupture apparatus was designed and built for testing filaments and wires having a diameter of 20 mils or less in a controlled atmosphere to prevent oxidation. Four tests may be run simultaneously at different stresses and temperatures (to 1427°C), and the stress-rupture life of each filament can be measured independently and automatically.

INTRODUCTION

INTEREST in composite materials in which high strength fibers or filaments are used to reinforce a lower strength matrix has prompted research on the physical and mechanical properties of the component materials as well as the composites themselves. In many cases the bulk properties of the matrix material may be used, but in the case of the filaments, the use of the bulk property data leads to erroneous conclusions since the mechanical properties of a fiber or a filament differ greatly from the properties of the material in bulk form.

For some applications at elevated temperatures, the tensile strength of a filament is of prime importance. However, for other applications the stress-rupture and creep properties of the filaments may be more important. Stress-rupture data of filaments have been obtained largely by using a tensile-test machine equipped to maintain a constant load on a heated filament, or by suspending a weight from a heated filament. The first method usually has been used when the time to rupture was short (less than 10 h), while the second method has been used for longer time tests. Two examples of the latter type of test apparatus are found in Newton, *et al.*[1] and Sinwell.[2] It is the purpose of this paper to describe a new machine capable of conducting long time stress-rupture tests on filaments under controlled conditions of atmosphere, stress, and temperature.

DISCUSSION

Design Considerations

Because of the small diameter of the wires to be tested (1–20 mils), several features not found in conventional stress-rupture machines had to be incorporated into the apparatus. The low loads (50–2000 g) on the specimens required that losses due to friction be kept to a minimum. Furthermore, since oxidation could cause premature failure of the materials under test, a protective atmosphere (vacuum or inert gas) was necessary. The entire test apparatus was housed under a bell jar which could be evacuated and back-filled with inert gas or which could maintain a protective vacuum. By using this system, it was possible to design the apparatus with a minimum of openings in the wall of the chamber and thereby reduce the possibility of leakage. This type of installation also eliminates the necessity for installing pull rods through O-ring seals or bellows for the application of load to the specimen. The only friction loss affecting the test was that encountered in the pulley over which the test filament rests. By using the method of determining the additional weight necessary to cause movement of balanced weights suspended over the pulley, it was found that the starting frictional loss was approximately 1% of the suspended load.

Since the filaments to be tested did not have a reduced cross section in the test area, the problem of the specimen fracturing in the grips had to be considered. It was circumvented by using a 15-in. length of filament as the test specimen, and by gripping the ends of the filament outside the furnace where they would be cool and less likely to fracture. The gauge length of the specimen is determined by the length of the effective heat zone of the furnace (~1 in.).

In order to increase the amount of data obtained during a single pump-down cycle, four identical test stands were placed in the same vacuum chamber. The apparatus is designed so that is is possible to run four different tests simultaneously at the same or different temperatures and loads.

Component Layout

The essential features of the apparatus are shown in Fig. 1. They consist of tantalum-wound resistance furnaces (a) mounted horizontally on a bedplate. The test specimen (b) is clamped to a fixed mount, strung through the furnace over a pulley, and attached to the appropriate weight (c). Prior to the start of the test the weights are supported by retractable weight supports (d), and the specimen is not loaded until it has reached the test temperature. Located directly under the weights are MicroSwitches (e), which are actuated by the fallen weights as the specimens break. Each MicroSwitch is connected in series with a furnace and an elapsed time meter. When the specimen fails, the MicroSwitch shuts off the furnace and the elapsed time meter.

[1] E. H. Newton, D. E. Johnson, and J. L. Sienczyk in *Symposium on Fibrous Materials* (Arthur D. Little Company, Cambridge, Massachusetts, 1963), p. 143.
[2] B. R. Sinwell, *Experimental Mechanics* (Society for Experimental Stress Analysis, Eastern, Pennsylvania, 1962), p. 176.

The entire assembly is covered with a glass or metal bell jar. The system is connected to a vacuum pumping system consisting of a 30-ft^3/min mechanical pump backing a 4-in. oil-diffusion pump. Pressures as low as 1×10^{-7} Torr have been measured in the test chamber using a cold cathode discharge gauge; when the furnaces are operating, pressures of $1\text{–}5\times10^{-6}$ Torr are usually encountered.

Power is supplied to the furnaces from a regulated 125-V power source. Power leads, timer leads, and thermocouple leads are fed into the environmental chamber through insulated glass-to-metal seals.

Individual furnace temperatures are monitored by measuring the output of platinum-platinum-13% rhodium thermocouples and recorded on a multi-point recording potentiometer. The couples are protected and supported by a two-hole insulating ceramic tube positioned parallel to the long axis of the furnace and parallel to the wire under test. The unprotected thermocouple bead is positioned within 0.5 mm of the wire specimen at the midpoint of the hot zone of the furnace. Since the thermocouple bead is not in acutal contact with the wire specimen, a calibration was necessary to correlate the temperature of the specimen to that of the sensing couple. To do this a butt-welded thermocouple was threaded through the furnace and fixed in the same manner as a test specimen, i.e., one insulated leg was passed through the fixed mount, while the other insulated leg was passed over the pulley and attached to the weight pan. The butt-welded bead was placed in the center of the hot zone and within 0.5 mm of the sensing couple. The readings of the two couples were then compared as the

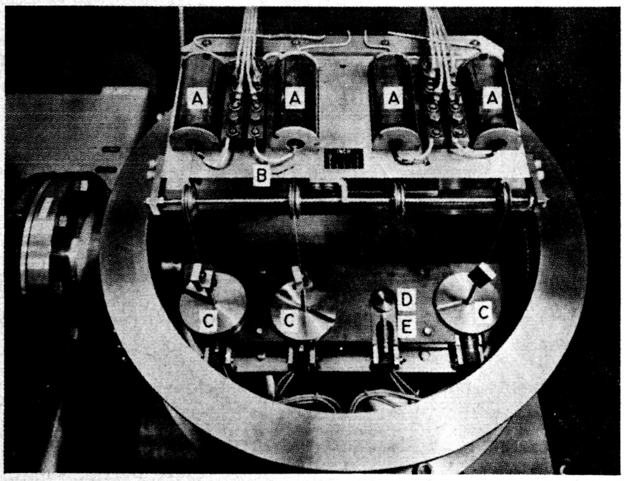

FIG. 1. Filament stress-rupture apparatus showing layout of furnaces, loading train, and MicroSwitches located within the environmental chamber.

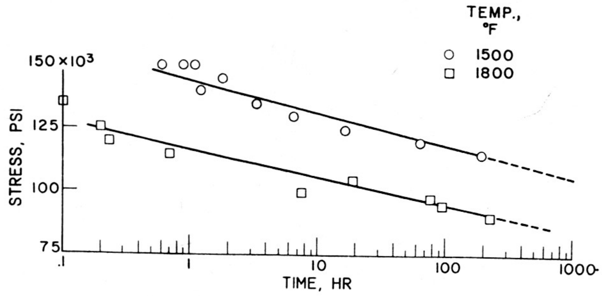

FIG. 2. Stress-rupture properties of as-received 5-mil-diam tungsten wire tested in vacuum.

furnace was heated and after it was allowed to stabilize at temperature. It was found that the two couples read within 2°C of each other after stabilization at 815°C for 1 h. Similar agreement was found at other temperatures.

Test Procedure

Test procedure is simple in that it is possible to position the specimens, load the weight pans, and evacuate the system to below 1×10^{-3} Torr in about 40 min. Subsequently, the furnaces are heated to the test temperature and allowed to stabilize. The furnaces are maintained at the desired test temperature by manually adjusting two Powerstats connected in series (one that permitted coarse, and the other fine, adjustments) with the regulated power source so that the heat input balances the heat loss. By using this system and the recording potentiometer, the temperature may be adjusted with a sensitivity of ±1°C (at 928°C), and during the course of a test, the temperature does not vary more than ±3°C as indicated by the potentiometer.

After the furnaces have been stabilized at the desired temperature, the specimens are loaded by lowering the weight supports. The timers are activated, and the test continues until all the specimens have failed.

Test Results

In order to evaluate the performance of this unit, stress-rupture tests were conducted on 5-mil-diam tungsten wire (General Electric type 218 CS) at temperatures of 815 and 982°C. The results obtained are shown in Fig. 2. From these results it can be seen that the 100-h stress-rupture strength for this wire was about 118 000 psi at 815°C while at 982°C it is about 92 000 psi. The limited scatter in these results shows that this apparatus performed well under the conditions of stress, temperature, and atmosphere used.